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THE UNIVERSITY OF ALBERTA

MEAT QUALITY PARAMETERS AS RELATED TO SEX, AGE AND CARCASS COMPOSITION OF BEEF CATTLE

by

John Gregory McAndrews

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

OF MASTER OF SCIENCE

DEPARTMENT OF ANIMAL SCIENCE

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THE UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate STUDIES AND Research, for acceptance, a thesis entitled " Meat Quality Parameters as Related to Sex, Age and Carcass Composition of Beef Cattle", submitted by John Gregory McAndrews in partial fulfilment of the requirements for the degree of Master of Science.

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Abstract

Carcasses from crossbred bulls (n=173) sired by Charolais and Simmental bulls were 11% heavier with 14% larger rib-eye area and 31% less rib fat depth than crossbred steers (n=165) sired by the same bulls, reared contemporaneously and slaughtered at the same ages. Purebred Shorthorn bulls (n=148) fed at a different location but slaughtered at the same ages produced carcasses 9% lighter, 17% smaller in rib-eye area and 16% greater in rib fat than the crossbred steers. All differences were significant ($P \leq .05$). Within each of these groups these measures of carcass composition were not correlated with objective color score (reflectance) or 24-hour pH. However, there were significant ($P \leq .05$) differences between groups in several measures of meat quality with carcasses from crossbred bulls highest in 24-hour pH, objective meat color score and water retention and lowest in transmission value (a measure of water soluble protein). Steer carcasses had the highest transmission values, were highest in glucose and glycogen content of meat (longissimus dorsi) and meat from steers was judged most tender by both subjective and objective measures.

Correlations of 24-hour pH with the various meat properties differed between groups. Within crossbred bull carcasses the highest correlations were found (24-hour pH

with color score (.77), water retention (.86), glucose (-.53), shear value (-.55) and subjective tenderness score (.69)), within crossbred steer carcasses, correlations were lowest for all traits measured. The percentage of carcasses with 24-hour pH greater than 5.7 were 53.5 for crossbred bulls, 16.5 for crossbred steers and 30.4 for Shorthorn bulls. For crossbred bulls, carcasses in the pH range 6.7 to 7.0 (n=20) averaged 119% in reflectance, 138% in water retention, 27% in transmission, 30% in glycogen and 12% in glucose of the averages observed for carcasses in the pH range 5.5-5.7, respectively (n=80).

It was evident that bulls were more susceptible and/or responsive than steers to pre-slaughter stress conditions which resulted in the biochemical changes responsible for the production of dark cutting beef. Shorthorn bulls appeared to be less stress susceptible than crossbred bulls but conditions of the experiment precluded direct comparisons.

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TABLE OF CONTENTS

		Page
1.	INTRODUCTION	1
2.	LITERATURE REVIEW	4
	2.1 Age of Animal	4
	2.2 Sex	7
	2.3 Breed	9
	2.4 Ante-Mortem Environment	10
3.	MATERIALS AND METHODS	16
	3.1 Population Studied	16
	3.2 Packing Plant Procedure	17
	3.3 Laboratory Procedure	18
	3.3.1 Sample Preparation	18
	3.3.2 Quality Evaluation	19
	3.3.3 Chemical Analysis	20
	3.3.4 Statistical Analysis	24
4.	RESULTS	25
5.	DISCUSSION	40
6.	CONCLUSION	49
7.	BIBLIOGRAPHY	50

LIST OF TABLES

Table		Page
1	Means and Standard Errors by Breed and Sex for Live Animal and Carcass Measurements.....	26
2	Means and Standard Errors by Breed and Sex for Chemical Composition of the Longissimus Dorsi.....	27
3	Simple Correlations of 24-Hour pH and Color with Muscle Percent and Total Rib Fat.....	28
4	Means and Standard Errors by Breed and Sex for Certain Longissimus Dorsi Muscle Properties.....	30
5	Means and Standard Errors by Age for Certain Longissimus Dorsi Muscle Properties of Crossbred Bulls.....	31
6	Means and Standard Errors by Age for Certain Longissimus Dorsi Muscle Properties of Crossbred Steers.....	32
7	Means and Standard Errors by Age for Certain Longissimus Dorsi Muscle Properties of Shorthorn Bulls.....	33
8	Simple Correlations Among 24-Hour pH Determinations and Other Muscle Properties of the Longissimus Dorsi Muscle.....	35
9	Means and Standard Errors for Certain Longissimus Dorsi Muscle Properties by 24-Hour pH for	

Crossbred bulls..... 37

10 Means and Standard Errors for 24-Hour pH Values by Panel Score and Shear Force for the Longissimus Dorsi Muscle of Crossbred Bulls..... 38

11 Simple Correlations Among Tenderness Evaluations and Other Muscle Properties of the Longissimus Dorsi..... 39

LIST OF FIGURES

Figure		Page
1	Relationship of Various Longissimus Dorsi Muscle Properties With 24-Hour pH From Crossbred Bulls.....	43
2	Relationship of Tenderness With 24-Hour pH in the Longissimus Dorsi Muscle.....	44

1. INTRODUCTION

Developments in the beef industry over the past two decades have resulted in substantial changes in the types of beef carcasses reaching retail outlets. Intense competition from other food products and changing consumer attitudes have resulted in research effort being directed toward identifying economical beef production systems, and relating the impact of the type of carcass accruing from these systems to consumer attitudes to beef. The introduction of the large European breeds of cattle to Canada, the rearing of bulls, feeding high energy rations from weaning, and other innovations have resulted in important genetic and environmental effects on beef carcass composition and quality characteristics. Emphasis has been on rapid growth and carcass muscling. Hence there is a tendency for carcass beef to be increasingly youthful, more heavily muscled and leaner at conventional slaughter weights. Since physiological maturity is reached at heavier weights, certain meat properties which influence quality factors are affected. For example, marbling or intra-muscular fatness, color, water retention properties, palatability and other consumer criteria of quality may be affected.

Regardless of the type of carcass from which beef is obtained, the quality of the meat produced is influenced by the physical and chemical changes which take place in the

muscle ante- and post-mortem. These changes are brought about by many factors, both genetic and non-genetic, which are as yet only partially understood. Energy requirements and physiological homeostasis compatible with life are supplied by the vascular system. With slaughter of the animal and consequent circulatory failure, post-mortem change in muscle commences and conversion of living muscle to meat begins (Lawrie 1962). Anaerobic glycolysis with the production of lactic acid is the final attempt of the muscle cell to maintain the living process. However, renewal of adenosine triphosphate (ATP) cannot be maintained for long and as ATP concentration decreases the muscle enters the state of rigor mortis (Bate-Smith and Bendall 1947, 1949). Qualitative properties of meat such as color, pH, palatability, water-holding capacity, emulsifying properties and others undergo change to a degree determined by the external and internal environment of the animal at and subsequent to death. Initial glycogen levels, extent and nature of endocrine stimulation at slaughter, ambient temperature post-mortem and other factors can all have crucial effects on post-mortem glycolysis and subsequent meat quality.

The objectives of this study were:

1. to study the effect of sex, breed and age of animal on meat quality,

2. to determine differences in levels of residual glucose and glycogen in longissimus dorsi muscle, and their relation to quality,

3. to determine if differences in lean and fat content of the carcass affect the quality of the meat and

4. to study the effects of distance of haul to the abbatoir on meat quality.

2. LITERATURE REVIEW

The consumer of beef has clearly established a preference for lean beef which must be tender, with satisfactory flavor and juiciness (Juillerat et al. 1972). Tenderness and leanness are the most important criteria of consumer acceptability (Bailey 1972; McFadyen and Stiles 1972); consequently it is appropriate to examine the factors influencing these criteria.

2.1 Age of Animal

Age appears to have little affect on meat tenderness when chronological age differences are small (Wipf et al. 1964 (9 to 15 months); Ritchey and Hostetler 1964 (8 to 15 months); Martin et al. 1971b (13 to 16 months)); but when wider differences in age are studied, meat tenderness decreases with increasing chronological age (Hiner and Hankins 1950 (2 1/2 years to 5 1/2 years); Jacobson and Fenton 1956 (8 to 20 months); Alsmeyer et al. 1959 (5 to 87 months); Tuma et al. 1962 (18 to 90 months); Palmer 1963 (5 to 99 months); Goll et al. 1965 (9 to>48 months); Walter et al. 1965a (9 to>48 months); Breidenstein et al. 1968 (9 to>48 months); Arthaud et al. 1970 (12 to 24 months)). Hunsley et al. (1971) reported significant differences in meat tenderness between 6- and 18-month old groups as measured by panel and shear with 6- and 18-month old groups

being more tender than 9-, 12-, and 15-month old groups. This report, however, included only 20 animals. Covington et al. (1970) using 60 carcasses, reported no significant differences in meat tenderness between maturity groups ranging from 12 to 38 months of age, which is at variance with other reports covering this range in age. Alsmeyer et al. (1959) found that age at slaughter accounted for only 8.1% of the variation in meat tenderness in animals ranging from 5 to 87 months of age. Tuma et al. (1962) and Henrickson and Moore (1965) found that the greatest decrease in meat tenderness occurred between 18 and 42 months of age. Hedrick et al. (1969) and Field et al. (1966) found that the chronological age effect was more pronounced in bulls than in steers. Martin et al. (1971b) reported a correlation of -0.3 between age at slaughter and panel tenderness for bull carcasses 13 to 16 months of age. Zinn et al. (1970) found that with an initial age of 250 $\pm$45 days, heifers reached a maximum tenderness after 150 days on feed while steers reached a maximum tenderness after 240 days on feed. This may be due to differences in age of maturity between steers and heifers with heifers maturing earlier than steers.

Other meat quality characteristics change with increase in animal age but the literature does not agree as to the type of change which takes place. As chronological age

increases, meat pH has been reported to increase (Walter et al. 1965a; 9 to>48 months) decrease (Tuma et al. 1963; 6 to 90 months) or remain the same (Breidenstein et al. 1968; 9 to>48 months) even though a wide range in age was studied in each case; meat texture becomes coarser (Walter et al. 1965a; Breidenstein et al. 1968) and meat color becomes darker (Tuma et al. 1963; Walter et al. 1965a; Breidenstein et al. 1968). Juiciness and flavor were found to increase (Jacobson and Fenton 1956; McBee and Wiles 1967; Arthaud et al. 1970) or remain the same (Tuma et al. 1962, 1963) and is in conflict since the former and latter researchers used age groups of 8 to 30 and 6 to 90 months respectively; moisture decreases and fat content increases (Jacobson and Fenton 1956; Goll et al. 1965; McBee et al. 1967); muscle protein decreases (McBee et al. 1967; beef carcasses 8 to 30 months) or changes little (Tuma et al. 1963; beef cows 6 to 90 months); flavor intensity score decreases (Goll et al. 1965: carcasses 9 to >48 months); or changes little (Arthaud et al. 1970; steers 12 to 24 months) and drip and coagulum decrease (Jacobson and Fenton 1956). Thus as animal age increases quality characteristics of the meat also change, but the type and extent of change occurring with increase in age have not been fully resolved. Differences between studies in sex of carcass and maturity range used results in different conclusions being drawn concerning the same quality factor.

2.2 Sex

Wide differences in meat quality attributable to sex have also been reported. Meat from intact males (i.e., bulls) has been stated to be less tender than meat from steers (Adams and Arthaud 1963; Aitken et al. 1963; Cahill 1964; Field et al. 1966; Arthaud et al. 1969; Glimp et al. 1971; Hunsley et al. 1971) and less tender than meat from heifers (Cahill 1964; Field et al. 1966) as measured by panel and shear. However, Field et al. (1966) found no differences in meat tenderness between bulls and steers and heifers at 300-399 days of age. Hedrick et al. (1969) using Warner-Bratzler shear values and sensory panel scores for meat tenderness, reported steaks from bulls less than 16 months of age were comparable in tenderness to steaks from steers and heifers of similar chronological age. Palmer (1963) found young bull beef to be as acceptable in tenderness as steer beef. Bailey et al. (1966a) found shear values of the longissimus dorsi of steers approximately 14 months of age were not significantly different to those of bulls of the same age. Martin et al. (1971b) discussing sex effects on beef tenderness indicated that bulls could receive superior tenderness ratings because of pre-slaughter influence producing dark cutting beef which is extremely tender. Where dark cutters were excluded bulls were less tender than heifers or steers. Price (1971b)

reported no difference between bulls and steers for tenderness in terms of practical meat quality. Martin and Fredeen (1973) reporting on results of a consumer study indicated bull carcasses had significantly higher shear values and lower consumer scores for tenderness and flavor than steer carcasses. These authors however observed that bull carcasses in their study which comprised youthful beef (approximately 400 days of age) were almost without exception rated satisfactory or better by the consumers for tenderness. Thus, to the consumer, meat from young bulls is as acceptable in tenderness as meat from steers of similar chronological ages.

Sex differences have been found for meat flavor and juiciness scores. Field et al. (1966) found flavor and juiciness scores for roasts from steers and heifers 600-699 days of age to be more desirable than from bulls of the same age. Arthaud et al. (1970) using animals from 12 to 24 months of age, found significant differences in muscle juiciness between bulls and steers. Other researchers using animals of younger ages found no sex differences in muscle juiciness and flavor (Glimp et al. 1971; Hedrick et al. 1969). Suess et al. (1966) found no differences in palatability attributable to sex for animals slaughtered between 386 and 455 kg (850-1000 lb.).

Sex also affects marbling and fat cover with meat from

bulls having less marbling and fat cover than meat from steers (Bailey et al. 1966a,b; Arthaud et al. 1969; Price 1971a; Martin and Fredeen 1973), and meat from steers having a lower fat content subcutaneously and intra-muscularly than meat from heifers (Bradley et al. 1966; Wilson et al. 1969; Link et al. 1970a; Marchello et al. 1970b). Terrell et al. (1969c) found that meat from steers was more uniformly marbled than meat from heifers.

Arthaud et al. (1969) reported meat from steers to have a finer texture and more desirable color than meat from bulls. Marchello et al. (1970) found while total pigment varied between sexes, no sex differences in muscle myoglobin content were observed.

2.3 Breed

There are many reports indicating significant differences between breeds for beef tenderness as measured by Warner-Bratzler shear values and/or taste panel scores (Cartwright et al. 1957; Kincaid 1962; Ramsey et al. 1963; Huffman et al. 1967a; Huffman et al. 1967b; Bramblett et al. 1971; Glimp et al. 1971). Various breeds and breed crosses were used by these authors.

Meat from purebred Brahman or Brahman crosses has been found to be significantly less tender than that of other breeds (Cartwright et al. 1957; Kincaid 1962; Ramsey et al.

1963; Palmer 1963; Huffman et al. 1967a; Huffman et al. 1967b) but there is some controversy as to whether a breed difference exists in tenderness among British breeds, British breed crosses and other breeds excluding Brahman. Some studies reported significant differences (Huffman et al. 1967b; Bramblett et al. 1971; Glimp et al. 1971) while other studies reported no significant differences in tenderness (Crocket et al. 1959; Klosterman et al. 1961; Ramsey et al. 1963). Crockett et al. (1959) and Bramblett et al. (1971) did not report age of animal at slaughter. However, in other reports where age at slaughter was 14 months or less a significant breed effect existed and where age was 20 months no significant breed effect was found. Thus, it would appear that as age increases breed differences in tenderness become overshadowed by the effect of increased age on quality.

2.4 Ante-Mortem Environment

It has long been realized that animals exposed to such stressors as cold, fatigue, anoxia, inanition and emotional excitement react by a release of hormones from the adrenal gland - first adrenalin from the adrenal medulla and then 17-hydroxycorticosterone and 11-deoxycorticosterone from the adrenal cortex (Selye 1936). The adrenalin causes the passage of potassium from the muscles to the blood and the breakdown of liver and muscle glycogens to glucose and

lactic acid. The 17-hydoxycorticosterone tends to restore the glycogen balance by gluconeogenesis from protein and the 11-deoxycorticosterone tends to restore the potassium balance. The release of these hormones from the adrenal cortex arises from stimulation of the latter by adrenocorticotrophic hormone (ACTH) produced in the anterior pituitary. This process is referred to as the "General Adaptation Syndrome" (Selye 1950; Hedrick 1965).

The factors capable of causing this disturbance are varied and can be associated with: activity, temperature, humidity, atmospheric pressure, oxygen tension, nutrition, pathology (e.g., microbial or parasitic invasion, physical injury, metabolic disorientation), artificial injurious agents (e.g., drugs and toxins, ionizing radiation, electric shock) and psychology (e.g., temperament, fear, light, sound) (Lawrie 1966).

The immediate effect of fatigue and muscular exercise is reduction of muscle glycogen whereas intermittent muscle exercise over an extended period increases the levels of muscle glycogen (Procter and Best 1932; Bate-Smith 1948). Long-term heavy exercise increases muscle glycogen content, decreases fat, water and collagen and may improve tenderness (Mitchell and Hamilton 1933). Enforced exercise of steers for 1 1/2 to 2 hours even after 14 day fasting failed to deplete muscle glycogen and raise the ultimate pH (Howard

and Lawrie, 1957a). Howard and Lawrie (1956) reported no difference in tenderness or pH attributable to severity of exercise or pre-slaughter fasting in steers.

Temperature stress may also affect muscle properties. Acute exposure to a cold environment may produce a high ultimate pH in cattle which is manifested in dark-cutting beef (Hall et al. 1944; Lawrie 1958). Shivering is the first compensatory reaction to a low temperature. Reserves of glycogen both in the liver and muscle are depleted by shivering (Hall et al. 1944; Lawrie 1958). The muscles of animals slaughtered in this condition may have an ultimate pH above the normal 5.5 (Lawrie 1966). Lewis et al. (1964) and Webb et al. (1964) indicated adverse effects on tenderness when comparing stressed steers to unstressed steers. However, where the ultimate pH remains very high (circa 6.0) the meat is characterized by dark color, high water retention properties and extreme tenderness (Martin et al. 1971a,b). These influences on tenderness have not been fully explained experimentally. However, dark-cutting beef may be accounted for by stress conditions which could result in: (1) prolonged release of adrenalin, and (2) subsequent establishment of low levels of muscle glycogen (Lawrie 1966).

Dark-cutting beef arises through the effect of the high pH in shifting the absorption of the muscle pigments to the

red end of the spectrum and increasing the cytochrome oxidase activity (Lawrie 1952). A high activity of this enzyme combined with the swollen structure of the fibres caused by the high pH (high pH is associated with high water binding capacity), depletes the oxygen available to form bright-red oxymyoglobin at the surface of the meat, thus permitting the purplish-red color of reduced myoglobin to predominate (Lawrie 1958).

Although fasting normally has no effect on glycogen reserves of cattle (Howard and Lawrie 1956), limited feeding pre-slaughter has been found to decrease tenderness scores, evaporation loss with cooking, and Munsell color values and increase shear force value and pH (Lewis et al. 1962).

Muscle glycogen reserves may be depleted by deficiencies in Cu, Co and Vitamin C and excesses of nitrate and fluoroacetate (Gallagher 1964). Deficiencies in Ca and Mg will cause increased excitability of muscle and a fast rate of onset of rigor mortis (Howard and Lawrie 1956).

Since it was difficult to deplete muscle glycogen reserves in steers sufficiently to raise the ultimate pH even by a combination of enforced pre-slaughter exercise with inanition, it is surprising to find such depletion in certain well fed and rested steers (Lawrie 1966). This condition was found to be caused by psychological stress

resulting in an animal with an excitable temperament (Howard and Lawrie 1956). Even at rest such animals exhibit continuous short range muscular twitching not manifested by marked movement of the body. This involuntary muscle activity reduces the equilibrium level of glycogen (Lawrie 1966). It is postulated that chronic release of adrenalin into the circulation of excitable animals achieves its effect on muscle glycogen stores by stimulation of phosphorylase b to phosphorylase a (Krebs and Fischer 1955; Ashmore et al. 1971) thus depleting glycogen by promoting lactic acid production in vivo in preference to mitochondrial respiration. The production of dark beef by adrenalin can be prevented by using beta adrenergic blocking agents which act at the cell membrane beta-adrenergic receptor sites (Ashmore et al. 1973).

The depletion of glycogen in muscle can also be achieved by the administration of: adrenalin (Hedrick et al. 1957; Hedrick et al. 1959; Hedrick et al. 1961; Judge and Stob 1963), tremorine (Bendall and Lawrie 1962), and electric shock (Hedrick et al. 1959; Lewis et al. 1961b, 1962, 1963a). The depletion of glycogen pre-slaughter by psychological or other stress resulting in changes in meat quality post-mortem is particularly severe in bulls, relative to steers or heifers (Martin et al. 1971b). However, evidence is lacking as to why this should occur.

Other research reporting stress effects on meat quality have indicated: elevated ultimate pH (Bouton et al. 1957; Lewis et al. 1961b, 1963; Judge and Stob 1963; Hedrick 1965), darker meat color (Hedrick et al. 1959; Lewis et al. 1961b, 1963a), increased water-holding capacity (Bouton et al. 1957; Hedrick 1965), and reduced cooking losses (Lewis et al. 1961a, 1962, 1963).

3. MATERIALS AND METHODS

3.1 Population Studied

The population studied comprised 173 crossbred bulls, 165 crossbred steers and 148 purebred Shorthorn bulls. The crossbred steers and bulls were of the same genetic background being sired by Charolais or Simmental bulls out of Hereford, Angus or Shorthorn dams from 21 contract herds. The same bulls were used in each herd. Breeds of bulls were used alternately and bulls within breed were used in sequence to inseminate the cows as they came into heat. Herd owners recorded birth dates, birth weights and ease of calving. Male calves were weaned between October 16, 1970 and October 30, 1970 and shipped to the Lacombe Research Station as each herd was completed and penned by herd. The day after arrival the calves were vaccinated, dehorned, given a vitamin ADE injection and half were selected at random and castrated. Calves were given a ration consisting of 1.4 kg of rolled oats per day plus long hay ad lib until November 2, 1970. From November 2 to November 20 the calves were brought up to full feed on a 70% grain and 30% hay ration. The grain ration consisted of 70% barley, 15% rolled oats, 10% beet pulp pellets and 5% protein supplement (32%). When the test calves averaged 318 kg the hay was reduced to 15%. The purebred Shorthorn bulls were raised at the Lacombe Research Station and the Brandon Research

Station. They were weaned October 13, 1970 and shipped to the Lethbridge Research Station on October 28, 1970. After arrival at Lethbridge they received similar treatment as the crossbred cattle at Lacombe and went on feed at approximately 200 days of age. The ration at Lethbridge consisted of a whole grain barley pellet without ad lib hay. The purebred Shorthorn bulls were individually fed at Lethbridge thus resulting in location differences in animal management. All cattle were slaughtered at 12, 13.5, or 15 months of age at a commercial packing plant in Red Deer, Alberta, and were slaughtered over a period of 18 weeks with 25 to 30 animals per week. This required an approximate seven hour truck haul from Lethbridge to Red Deer for the Shorthorn bulls while the crossbred bulls and steers were subjected to approximately a one hour truck haul from Lacombe to Red Deer. In addition to the differences in stress associated with distance of haul to slaughter, the Shorthorns were grouped immediately prior to shipment.

3.2 Packing Plant Procedure

Slaughtering commenced within 1 hour after arrival at the plant. Stunning was done with a captive bolt pistol, normal packing plant kill line procedures were followed and the carcasses were washed, shrouded and moved into a cooler for chilling at 2 to 4 C. Approximately twenty-four hours after slaughter the left side of the carcass was ribbed at

the 11th-12th rib interface. Three measures of fat over the rib-eye, one directly over the center of the Longissimus Dorsi muscle (LD), and the other two at points which bisected the top and bottom halves of the LD (Fredeen and Weiss, 1970); rib-eye area (determined with a transparent grid ruled in 1.61 sq. cm squares) and pH readings of the LD using a portable pH meter with a pointed probe electrode ("Portomatic 175" pH meter, Instrumentation Laboratories) were taken.

After hanging for 6 days, at 2 to 4 C the left side of the carcass was broken into nine cuts: chuck, rib, short loin, sirloin butt, round, brisket, shank, flank, and plate (Fredeen et al. 1971). Each of the five major primal cuts (chuck, rib, short loin, sirloin butt and round) was dissected into muscle, fat and bone to determine carcass composition. The brisket, shank, flank and plate were not included, since they represent only a small proportion of the lean in the carcass. The LD muscle (from the rib and the short loin) was taken back to the laboratory for meat quality evaluation.

3.3 Laboratory Procedure

3.3.1 Sample Preparation

Approximately 250 g of the LD anterior to the 11th-12th rib interface was completely trimmed of external fat and ground by passing it through a grinder three times to ensure

uniformity of sample. To ensure a fresh cut surface, a slice was first removed from the posterior end of the rib. The ground LD was placed in a glass jar with a lid and frozen at -20C for four months before analysis.

3.3.2 Quality Evaluation

Two steaks, 2.5 cm in width were cut from each LD posterior to the 11-12th rib interface after an initial slice was removed to ensure a fresh cut surface on both sides of each steak. The first steak was cooked in a microwave oven on a fiber glass tray to medium rare (evaluated subjectively pink in the center) and cooled overnight in a refrigerator at 2 to 4 C. Ten steaks from different animals were cooked at one time. Cooking time per steak varied from 15 to 20 minutes. The following day three cores, each 2 cm in diameter, were taken from central, medial and lateral locations and were evaluated for tenderness using a Warner-Bratzler shear apparatus. Readings were recorded on a chart recorder using a scale from 0 to 100 representing 13,000 g of force. Cores were close to room temperature (20 C) at shear time.

Objective color readings (measured by means of a photoelectric brightness meter, Ernst Schutt Laboratories, Gottingen, Germany) were taken on the second steak (using a scale from 0 to 100 with increasing color score corresponding to darker color) after the bright red color

characteristic of oxymyglobin was produced by exposing the surface of the steak to the air for approximately 20 min. Ten steaks were then cooked in a microwave oven to medium rare and evaluated for tenderness by an experienced taste panel of six people using a 1 to 9 descriptive scale with 1 being very tough and 9 being very tender. Alternate panel members were used only if the need arose. Six cores removed from each steak were randomly assigned to the panel members for tenderness evaluation. Panel members were not instructed as to how to chew the cores.

3.3.3 Chemical Analysis

Turbidity measurements (% transmission) for water soluble protein of the ground LD were taken using the method of Hart (1962). Ten g of ground longissimus dorsi plus 10 ml of distilled water were homogenized at 2 to 4 C in a Virtis homogenizer at 75% of maximum speed for fifteen minutes. The homogenized sample was poured into a 50 ml centrifuge tube, brought up to 30 ml total volume with distilled water, thoroughly mixed, covered with Parafilm and stored at 2 to 4 C overnight. The following day the sample was centrifuged at 26,000 g's and 4 C for 20 min. The supernatant liquid was poured through a filter paper (S&S 589) to remove solidified fat particles. One ml of the filtered supernatant was mixed with 5 ml of a citric acid phosphate buffer (pH 4.6) at room temperature. Percent

transmission was read after 30 min against a blank consisting of 5 ml of water and 1 ml of supernatant and at a wavelength of 600 nm.

Water retention was carried out using the method of Herring et al. (1971). Approximately 20 g of ground LD was weighed into a tared 50 ml test tube. The test tube was centrifuged for 60 min at 37,000 g's and 4 C. The supernatant fluid was poured into weighed 50 ml beakers and the weight of juice extracted was recorded. The juice retained was expressed as a percent of original moisture to eliminate variations in ether extractible material of the original muscle.

The ground LD was analysed for moisture and fat, by a method adapted from A.O.A.C., 1965. Approximately 100 g of ground LD was weighed into tared aluminum beakers and placed in a drying oven at 105 degrees C overnight. The following day the beakers were reweighed to determine moisture loss, expressed as a percentage of the weight of the original sample. The dried meat samples were pulverized, an aliquot weighed into tared alundum thimbles, then placed in a Soxhlet extractor for 16 hr for ether extraction of fat by di-ethyl ether. The thimbles were removed from the extractor, air dried to remove ether fumes, oven dried to remove any moisture present, and weighed to determine fat extracted. Percent fat was calculated on a dry matter

basis. Percent protein was calculated by ashing the dried-defatted samples overnight at 600 C, weighing the thimbles plus ash, calculating percent ash and determining percent protein by difference (100%-(% moisture + % fat + % ash)).

Glucose in the ground LD was determined using the Greenberg and Glick modification of the glucose oxidase method (Glick 1963). Ten g of frozen sample was homogenized with 45 ml of distilled water for 15 min at 2 to 4 C in a Virtis homogenizer at 75% of top speed. The homogenized sample was poured into a 50 ml centrifuge tube and centrifuged at 37,000 g's and 4 C for 15 min. The supernatant was filtered to remove solidified fat and the volume measured. Eight ml of supernatant was pipetted into a 100 ml volumetric flask and brought up to volume with distilled water. Two ml of diluted extract plus 3 ml of glucose oxidase solution was pipetted into a sample test tube. Two ml of diluted extract plus 3 ml of boiled glucose oxidase solution (enzyme destroyed by heat) were also pipetted into a blank test tube. Two glucose standards were used: 10 ug/ml and 20 ug/ml. Two ml of standard plus 3 ml of glucose oxidase solution were pipetted into the standard test tube. Two ml of distilled water plus 3 ml of glucose oxidase solution were pipetted into the standard blank. Sample and standard tubes were digested at 37 C for 45 min and then optical density (O.D.) was read at 400 nm. Glucose

was calculated using the formula

$$\text{ug glucose/g meat} = 1.667\ AS$$

Where

A=ml of aliquot

S=ug of glucose in subsample

$$S = \frac{\text{ug of glucose in standard} \times \text{O.D. of sample}}{\text{O.D. of standard}}$$

1.667 = dilution factor

Glycogen was determined using the method of Roe and Dailey (1966) with some adaptations. One g of frozen ground LD was added to 3 ml of 1N NaOH in a graduated centrifuge tube. Two standards were prepared: 0.1 mg glycogen/ml and 0.2 mg glycogen/ml. The samples and standards were fitted with a condenser and placed in a boiling water bath for 1.5 hr to digest the tissue. After cooling to room temperature, 6 ml of 1N perchloric acid was added to deproteinize the alkaline digest and the volume was brought to 10 ml with distilled water. After standing for 15 min the samples and standards were filtered through acid washed paper. One ml of filtered extract was pipetted into a centrifuge tube, 2 ml of 95% ethanol solution was added and the tubes were allowed to stand overnight at room temperature to precipitate the glycogen. The following day the tubes were centrifuged for 30 min at 4,000 rpm, and room temperature; the supernatant was decanted and the tubes were allowed to drain at a 45 degree angle for 10 min. Five ml of 80%

ethanol solution was added and the tubes were centrifuged at 4,000 rpm for 10 min, the supernatant was decanted and the tubes were allowed to drain at a 45 degree angle for 10 min. This step was then repeated. Two ml of distilled water was added to the tubes, they were agitated and 10 ml of Anthrone reagent was added to obtain the color production. The tubes were stoppered, mixed and fitted with condensers. A blank was prepared with 2 ml of distilled water and 10 ml of Anthrone reagent. The tubes were placed in a boiling water bath for 15 min, cooled and the optical density (O.D.) was read at 620 nm. The formula used for calculation was

mg glycogen/100 g of tissue =

$$\frac{Du}{Ds} \times \text{mg glucose in standard} \times \text{dilution} \times .09 \times \frac{100}{\text{g of tissue}}$$

Where,

Du = optical density unknown sample

Ds = optical density standard

Dilution = 10

0.9 = factor for converting glucose value to glycogen value

3.3.4 Statistical Analysis

Means and standard errors were derived for sex, location, breed, and treatment (slaughter age) groups. T-tests were used to determine significant differences between means. Correlation coefficients were derived among all variables.

4. RESULTS

Preliminary analysis showed little difference between the Charolais and Simmental crossbred bulls and steers so for analysis of quality factors the two breeds were combined. Means and standard errors for live animal and carcass composition measurements are presented in Table 1. The crossbred bulls had significantly greater live and carcass weight significantly larger rib-eye area, significantly less total rib-fat depth and significantly greater percent muscle than the crossbred steers which in turn had significantly greater live and carcass weight, had significantly larger rib-eye area, signficantly less total rib-fat depth and significantly greater percent muscle than the Shorthorn bulls.

Means and standard errors by breed and sex for chemical composition of the LD are presented in Table 2. Crossbred bull LD had significantly more moisture than crossbred steers LD or Shorthorn bulls LD. The LD of crossbred bulls and steers had significantly more protein than the LD of Shorthorn bulls. Crossbred bulls LD had significantly less ether extract than crossbred steers LD which had significantly less ether extract than Shorthorn bulls LD. Correlations for muscle and total rib-fat depth with pH and meat color were small for all sex-breed groups (Table 3).

TABLE 1.

MEANS AND STANDARD ERRORS BY BREED AND SEX FOR LIVE ANIMAL AND CARCASS MEASUREMENTS

	Crossbred				Shorthorn	
	Bulls (N = 173)		Steers (N = 165)		Bulls (N = 148)	
Variable	Mean	Std. Error	Mean	Std. Error	Mean	Std. Error
Live Weight (kg)	514[a]	4.6	474[b]	4.6	433[c]	5.7
Carcass Weight (kg)	295[a]	3.4	264[b]	2.9	240[c]	3.7
Rib-eye Area (sq cm)	89.3[a]	0.8	76.5[b]	0.6	63.7[c]	0.7
Total Rib Fat (cm)	2.79[a]	0.08	4.04[b]	0.08	4.67[c]	0.13
Muscle[d]	58.8[a]	0.2	54.4[b]	0.2	51.9[c]	0.2

a-c Means in the same row with different superscripts are significantly different ($P \leq 0.05$)

d Weight of muscle in primal cuts as a percentage of carcass weight

TABLE 2.

MEANS AND STANDARD ERRORS BY BREED AND SEX FOR CHEMICAL COMPOSITION OF THE LONGISSIMUS DORSI

	Crossbred				Shorthorn	
	Bulls (N = 173)		Steers (N = 165)		Bulls (N = 148)	
Variable	Mean	Std. Error	Mean	Std. Error	Mean	Std. Error
Moisture (%)	74.7[a]	0.1	73.6[b]	0.1	73.6[b]	0.1
Protein (%)	22.2[a]	0.1	22.1[a]	0.1	21.6[b]	0.1
Ether Extract (%) (dry basis)	8.2[a]	0.2	12.3[b]	0.4	14.1[c]	0.4
Ash (%)	1.01	0.005	0.99	0.004	0.97	0.005

a-c Means in the same row with different superscripts are significantly different ($P \leq 0.05$)

TABLE 3.

SIMPLE CORRELATIONS OF 24-HOUR pH AND COLOR WITH MUSCLE PERCENT AND TOTAL RIB FAT

	Crossbred				Shorthorn	
	Bulls		Steers		Bulls	
	pH	Color	pH	Color	pH	Color
Muscle[a]	0.12	-0.03	0.22	0.19	0.06	-0.04
Total Rib Fat (cm)	-0.22	-0.08	-0.18	-0.21	-0.17	-0.04

a Weight of muscle in primal cuts as a percentage of carcass weight

Means and standard errors for the quality variables measured on the LD are presented in Table 4. Crossbred bulls had significantly higher reflectance values, pH values and water retention and significantly lower percent transmission than crossbred steers. Crossbred steers had similar reflectance values and water retention but significantly lower 24-hour pH values and significantly higher transmission values than Shorthorn bulls. Crossbred bulls and Shorthorn bulls were significantly less tender both for shear force measures and taste panel score than the crossbred steers and the latter had significantly more residual glucose and glyocgen than either group of bulls.

No age effects on meat quality were found for the crossbred bulls (Table 5) but age effects on meat quality were found for the crossbred steers (Table 6) and the Shorthorn bulls (Table 7). Meat from crossbred steers was significantly lighter colored, significantly more tender and had significantly higher water retention values at 15 months of age than at 12 months of age. Glucose was significantly higher at 12 months of age than at 13.5 or 15 months of age. Glycogen, transmission and 24-hour pH showed no significant differences between ages. Meat from Shorthorn bulls became significantly tougher between 12 and 13.5 months of age as measured by Warner-Bratzler shear but not taste panel. Glucose was significantly higher at 12 months of age than at

TABLE 4.

MEANS AND STANDARD ERRORS BY BREED AND SEX FOR CERTAIN LONGISSIMUS DORSI MUSCLE PROPERTIES

	Crossbred								
	Bulls			Steers			Shorthorn Bulls		
Variable	N	Mean	Std. Error	N	Mean	Std. Error	N	Mean	Std. Error
Reflectance (%)	172	79.6[a]	0.57	165	72.2[b]	0.40	148	72.6[b]	0.49
24-Hour pH	173	6.00[a]	0.04	164	5.68[b]	0.02	148	5.75[c]	0.02
Water Retention (%)	111	54.9[a]	0.74	107	49.5[b]	0.34	92	49.9[b]	0.48
Transmission (%)	111	66.1[a]	3.24	107	95.4[b]	1.46	91	81.7[c]	3.13
Glucose (µg/g)	169	1096.0[a]	34.7	164	1275.0[b]	36.0	145	1105.0[a]	41.8
Glycogen (mg/g)	169	0.459[a]	0.05	163	1.06[b]	0.07	145	0.448[a]	0.05
Taste Panel Tenderness[1]	172	5.84[a]	0.10	165	6.69[b]	0.07	148	5.81[a]	0.09
Warner-Bratzler Shear[2]	173	52.4[a]	1.35	165	42.0[b]	0.88	148	51.5[a]	1.13

a-c Means in the same row with different superscripts are significantly different ($P \leq 0.05$)

[1] Taste panel tenderness was measured by means of a descriptive scale running from 1 to 9 with 1 being very tough and 9 being very tender.

[2] Warner-Bratzler shear was measured on a linear scale running from 0 to 100 with 100 representing 13000 grams of force to shear a 2 centimeter diameter core.

30

TABLE 5.

MEANS AND STANDARD ERRORS BY AGE FOR CERTAIN LONGISSIMUS DORSI MUSCLE PROPERTIES OF CROSSBRED BULLS

	12 Months N = 56		13.5 Months N = 59		15 Months N = 58	
Variable	Mean	Std. Error	Mean	Std. Error	Mean	Std. Error
Reflectance (%)	78.2	1.0	80.2	1.1	80.2	0.9
24-Hour pH	6.1	0.07	6.0	0.07	5.9	0.05
Water Retention (%)	---[1]	---[1]	54.7	1.3	55.1	0.8
Transmission (%)	---[1]	---[1]	68.0	4.8	64.4	4.7
Glucose (ug/g)	1136	81	1096	52	1057	43
Glycogen (mg/g)	0.438	0.08	0.507	0.07	0.431	0.10
Taste Panel Tenderness[2]	6.0	0.2	6.0	0.2	5.6	0.2
Warner-Bratzler Shear[3]	50.4	2.6	50.4	2.1	56.5	2.2

[1] Values for water rentention and transmission are missing for the 12 months age group due to initial errors encountered in reproducing these procedures.

[2] Taste panel tenderness was measured by means of a descriptive scale running from 1 to 9 with 1 being very tough and 9 being very tender.

[3] Warner-Bratzler shear was measured on a linear scale running from 0 to 100 with 100 representing 13000 grams of force to shear a 2 centimeter diameter core.

TABLE 6.

MEANS AND STANDARD ERRORS BY AGE FOR CERTAIN LONGISSIMUS DORSI MUSCLE PROPERTIES OF CROSSBRED STEERS

	12 Months N = 57		13.5 Months N = 52		15 Months N = 56	
Variable	Mean	Std. Error	Mean	Std. Error	Mean	Std. Error
Reflectance (%)	73.2[d]	0.6	72.8[de]	0.7	70.8[e]	0.7
24-Hour pH	5.7	0.03	5.7	0.03	5.6	0.02
Water Retention (%)	47.5[d]	0.5	49.0[de]	0.7	50.3[e]	0.4
Transmission (%)	98.6	1.4	91.9	3.2	97.4	1.5
Glucose (ug/g)	1497[d]	90	1172[e]	34	1148[e]	29
Glycogen (mg/g)	1.136	0.13	1.160	0.13	0.877	0.09
Taste Panel Tenderness[1]	6.4[d]	0.1	6.7[de]	0.1	7.0[e]	0.1
Warner-Bratzler Shear[2]	45.2[d]	1.3	42.2[de]	1.9	38.4[e]	1.3

d-f Means in the same row with different superscripts are significantly different ($P \leq 0.05$)

[1] Taste panel tenderness was measured by means of a descriptive scale running from 1 to 9 with 1 being very tough and 9 being very tender.

[2] Warner-Bratzler shear was measured on a linear scale running from 0 to 100 with 100 representing 13000 grams of force to shear a 2 centimeter diameter core.

TABLE 7.

MEANS AND STANDARD ERRORS BY AGE FOR CERTAIN LONGISSIMUS DORSI MUSCLE PROPERTIES OF SHORTHORN BULLS

	12 Months N = 51		13.5 Months N = 49		15 Months N = 48	
Variable	Mean	Std. Error	Mean	Std. Error	Mean	Std. Error
Reflectance (%)	72.1	0.82	73.0	0.80	72.5	0.95
24-Hour pH	5.8	0.04	5.7	0.04	5.7	0.04
Water Retention (%)	---[1]	---[1]	47.9[d]	0.70	51.0[e]	0.53
Transmission (%)	---[1]	---[1]	81.5	4.6	85.5	4.0
Glucose (ug/g)	1350[d]	111	986[e]	30	983[e]	32
Glycogen (mg/g)	0.590	0.09	0.350	0.07	0.410	0.08
Taste Panel Tenderness[2]	5.8	0.16	5.6	0.16	5.9	0.15
Warner-Bratzler Shear[3]	48.7[d]	1.9	55.0[e]	2.1	50.8[de]	1.8

d-e Means in the same row with different superscripts are significantly different ($P \leq 0.05$)

[1] Values for water retention and transmission are missing for the 12 months age group due to initial errors encountered in reproducing these procedures.

[2] Taste panel tenderness was measured by means of a descriptive scale running from 1 to 9 with 1 being very tough and 9 being very tender.

[3] Warner-Bratzler shear was measured on a linear scale running from 0 to 100 with 100 representing 13000 grams of force to shear a 2 centimeter diameter core.

13.5 or 15 months of age. Water retention was significantly higher at 15 months of age than at 13.5 months of age. No significant differences were found for reflectance, 24-hour pH, transmission or glycogen.

Ranking of the three sex-breed groups in terms of the proportion with 24-hour pH values greater than 5.7 (a criterion for dark cutting beef, Webb et al. 1967) was crossbred bulls greater than Shorthorn bulls which were greater than crossbred steers. The crossbred bulls and steers which were group fed and subjected to a one-half hour truck haul to the packing plant had 53.5 and 16.5 percent of carcasses exceeding pH 5.7 respectively. The Shorthorn bulls, individually fed, mixed during shipping and subjected to a seven hour truck haul to the packing plant had 30.4 percent exceeding pH 5.7.

Correlations for 24-hour pH with several muscle properties (Table 8) were generally similar for the two bull groups while steers invariably gave lower correlations. The bull-steer differences were particularly evident for water retention (0.8 vs 0.1) and transmission value (0.7 vs 0.3). The highest correlations with glycogen (-0.37), glucose (-0.53), shear (-0.55) and taste panel tenderness (.69) were observed for the crossbred bulls. This group also exhibited the highest average pH at 24-hours and the greatest variance in this trait (Table 4). The association between pH and

TABLE 8.

SIMPLE CORRELATIONS AMONG 24-HOUR pH DETERMINATIONS AND OTHER MUSCLE PROPERTIES OF THE LONGISSIMUS DORSI MUSCLE

	Shorthorn	Crossbred	
	Bulls N = 148	Bulls N = 173	Steers N = 164
Reflectance (%)	.74	.77	.57
Water Retention (%)	.82	.86	.10
Transmission (%)	-.74	-.67	-.34
Glucose (ug/g)	-.21	-.53	-.06
Glycogen (mg/g)	-.24	-.37	-.20
Taste Panel Tenderness[1]	.23	.69	-.07
Warner Bratzler Shear[2]	-.12	-.55	.14

[1] Taste panel tenderness was measured by means of a descriptive scale running from 1 to 9 with 1 being very tough and 9 being very tender.

[2] Warner-Bratzler shear was measured on a linear scale running from 0 to 100 with 100 representing 13000 grams of force to shear a 2 centimeter diameter core.

several characteristics measured on the LD is illustrated in Table 9 for crossbred bulls. As pH increased from 5.5 to 7.0, significant increases ($P \leq 0.05$) were recorded in reflectance (75.0 to 89.3%) and water retention (50.6 to 70.0%) with significant decreases ($P \leq 0.05$) in transmission value (87.8 to 23.9%), glucose (1250 to 415 ug/g of tissue) and in glycogen (0.714 to 0.059 mg/g of tissue). Tenderness as measured by panel score and Warner-Bratzler shear increased significantly above pH range 6.3-6.4 and 6.5-6.6 respectively (Table 10). Below these pH ranges no significant differences in tenderness were observed in subjective (taste panel) scores or objective (Warner-Bratzler) shear values. Correlations between panel score and Warner-Bratzler shear were -0.76, -0.64 and -0.67 for crossbred bulls, Shorthorn bulls and crossbred steers, respectively (Table 11). Correlations of Warner-Bratzler shear and taste panel tenderness with quality properties were similar for Shorthorn bulls and crossbred steers with both groups generally giving lower correlations than crossbred bulls. The highest correlations with reflectance (0.45), water retention (0.61) and glucose (0.42) were observed for the crossbred bulls.

TABLE 9.

MEANS AND STANDARD ERRORS FOR CERTAIN LONGISSIMUS DORSI MUSCLE PROPERTIES BY 24-HOUR pH FOR CROSSBRED BULLS

	Reflectance (%)			Water Retention (%)			Transmission (%)			Glucose (ug/g)			Glycogen (mg/g)		
pH	N	Mean	Std. Error	N	Mean	Std. Error	N	Mean	Std. Error	N	Mean	Std. Error	N	Mean	Std. Error
5.5-5.7	80	75.0[a]	0.5	53	50.6[a]	0.6	53	87.8[a]	3.4	79	1250[a]	37	79	0.714[a]	0.081
5.8-6.0	39	78.9[b]	1.1	27	53.9[b]	1.1	26	62.4[b]	5.4	38	1210[ab]	68	38	0.325[b]	0.096
6.1-6.6	33	85.5[c]	1.1	22	60.2[c]	1.4	22	37.8[c]	5.5	31	1005[b]	81	32	0.219[b]	0.075
6.7-7.0	20	89.3[d]	0.6	9	70.0[d]	0.9	10	23.9[c]	3.9	20	412[c]	58	19	0.059[b]	0.007

a-c Means in the same column with different superscripts are significantly different ($P \leq 0.05$)

TABLE 10.

MEANS AND STANDARD ERRORS FOR 24-HOUR pH VALUES BY PANEL SCORE AND SHEAR FORCE FOR THE LONGISSIMUS DORSI MUSCLE OF CROSSBRED BULLS.

		Panel Score[1]		Warner-Bratzler Shear[2]	
24-Hour pH Values	N	Mean	Std. Error	Mean	Std. Error
5.5 - 5.6	42	5.4[a]	0.13	55.4[a]	2.1
5.7 - 5.8	56	5.4[a]	0.13	56.8[a]	2.2
5.9 - 6.0	21	5.2[a]	0.26	62.4[a]	3.6
6.1 - 6.2	12	5.6[a]	0.40	60.4[a]	4.5
6.3 - 6.4	8	5.8[a]	0.34	52.4[ab]	5.1
6.5 - 6.6	13	6.8[b]	0.33	41.4[b]	3.3
6.7 - 6.8	10	8.1[c]	0.18	29.3[c]	1.4
6.9 - 7.0	10	8.3[c]	0.12	23.5[d]	1.3

a-d Means in the same column with different superscripts are significantly different ($P \leq 0.05$)

[1] Taste panel tenderness was measured by means of a descriptive scale running from 1 to 9 with 1 being very tough and 9 being very tender.

[2] Warner-Bratzler shear was measured on a linear scale running from 0 to 100 with 100 representing 13000 grams of force to shear a 2 centimeter diameter core.

TABLE 11.

SIMPLE CORRELATIONS AMONG TENDERNESS EVALUATIONS AND OTHER MUSCLE PROPERTIES OF THE LONGISSIMUS DORSI

	Shorthorn		Crossbred			
	Bulls N = 148		Bulls N = 173		Steers N = 164	
	Shear[2]	Panel[1]	Shear[2]	Panel[1]	Shear[2]	Panel[1]
Taste Panel Tenderness[1]	-.64		-.76		-.67	
Reflectance (%)	.14	-.04	-.17	.45	.21	-.23
Water Retention (%)	-.14	.27	-.45	.61	.04	.07
Transmission (%)	-.03	-.06	.22	-.34	-.38	.22
Glucose (ug/g)	-.10	.01	.26	-.42	.12	-.14
Glycogen (mg/g)	-.19	.04	-.10	-.10	-.22	.05

[1] Taste panel tenderness was measured by means of a descriptive scale running from 1 to 9 with 1 being very tough and 9 being very tender.

[2] Warner-Bratzler shear was measured on a linear scale running from 0 to 100 with 100 representing 13000 grams of force to shear a 2 centimeter diameter core.

5. DISCUSSION

Dark cutting (high pH) beef is considered undesirable because it detracts from uniformity of product appearance in retail display counters. Further, consumers tend to associate dark color with staleness of product. Thus, whether or not the reasons are valid in terms of actual eating quality, meat color is designated as an important criterion of quality in grading and merchandising of beef. For this reason it is of considerable importance to identify the causes of high pH beef and to point the way toward pre- and/or post-slaughter procedures to minimize the incidence of dark cutters.

It has been postulated that high pH beef is caused by stress conditions which in some animals may result in: (1) prolonged release of adrenalin; and (2) establishment of low levels of muscle glycogen (Lawrie 1966). Further, the chronic release of adrenalin into the circulation in stress susceptible animals has been postulated to achieve its effect on muscle glycogen stores by stimulation of phosphorylase b to phosphorylase a (Krebs and Fischer, 1955; Ashmore et al. 1971) thus depleting glycogen by promoting lactic acid production in vivo in preference to mitochondrial respiration. Experimentally the production of dark cutting beef by subcutaneous administration of adrenalin has been prevented by using beta-adrenergic

blocking agents which act at the cell membrane beta-adrenergic receptor sites (Ashmore et al. 1973).

Pre-slaughter handling procedures represent one source of ante-morten stress which influences post-mortem changes in the carcass and some of the factors involved have been well documented (Hedrick 1965; Martin et al. 1971b; Martin and Fredeen, 1974; Fredeen et al. 1974). Fredeen et al. (1974) reported that a long period of pre-slaughter stress associated with transport to slaughter (7 hours) resulted in higher 24-hour pH, increased tenderness and darker meat color in crossbred bulls relative to straight bred Hereford steers subjected to the same transport conditions.

Important sex differences in response to pre-slaughter stress were also observed in the present study. Judging from differences observed in several meat quality traits, crossbred bulls were much more susceptible to ante-morten handling and transportation (1 hour) stresses than steers of the same breeding and age subjected to the same feeding and pre-slaughter management. It was also observed that purebred Shorthorn bulls which were presumably subjected to much greater transportation stress (7 hours) immediately pre-slaughter were intermediate in stress susceptibility to the crossbred bulls and steers. Using the criterion of "dark cutting" proposed by Webb et al. 1967 (pH greater than 5.7), the proportion of dark cutters in each group was

53.5% for crossbred bulls, 30.4% for Shorthorn bulls and 16.5% for crossbred steers. The difference in percent dark cutting beef between the two bull groups may indicate a difference in stress susceptibility and/or response between the crosses and straight breeds.

For examination of the post-mortem changes which occurred in meat characteristics it is most informative to direct attention to the group exhibiting the greatest range of response to pre-slaughter conditions (i.e. crossbred bulls). For this group, 24-hour pH was highly correlated with meat color (.77), water retention (.86), transmission (-.67), shear (-.55), subjective tenderness score (.69), glucose (-.53) and glyocgen (-.37). Thus as 24-hour pH increased (from 5.5 to 7.0) meat color darkened, water retention and tenderness increased, transmission decreased and residual levels of glucose and glycogen decreased.

Responses to pH change over the range was reasonably linear for reflectance, water retention, and transmission value but not linear for glucose or glycogen (Figure 1).

As noted from Figure 2, Warner-Bratzler shear force measures tended to increase in the pH range 5.5 to 6.2 but reduced rapidly and in a linear fashion after pH 6.2 to a low value of 23.5 at pH 7.0. Thus the correlation of Warner-Bratzler shear with pH (-.55) would have been

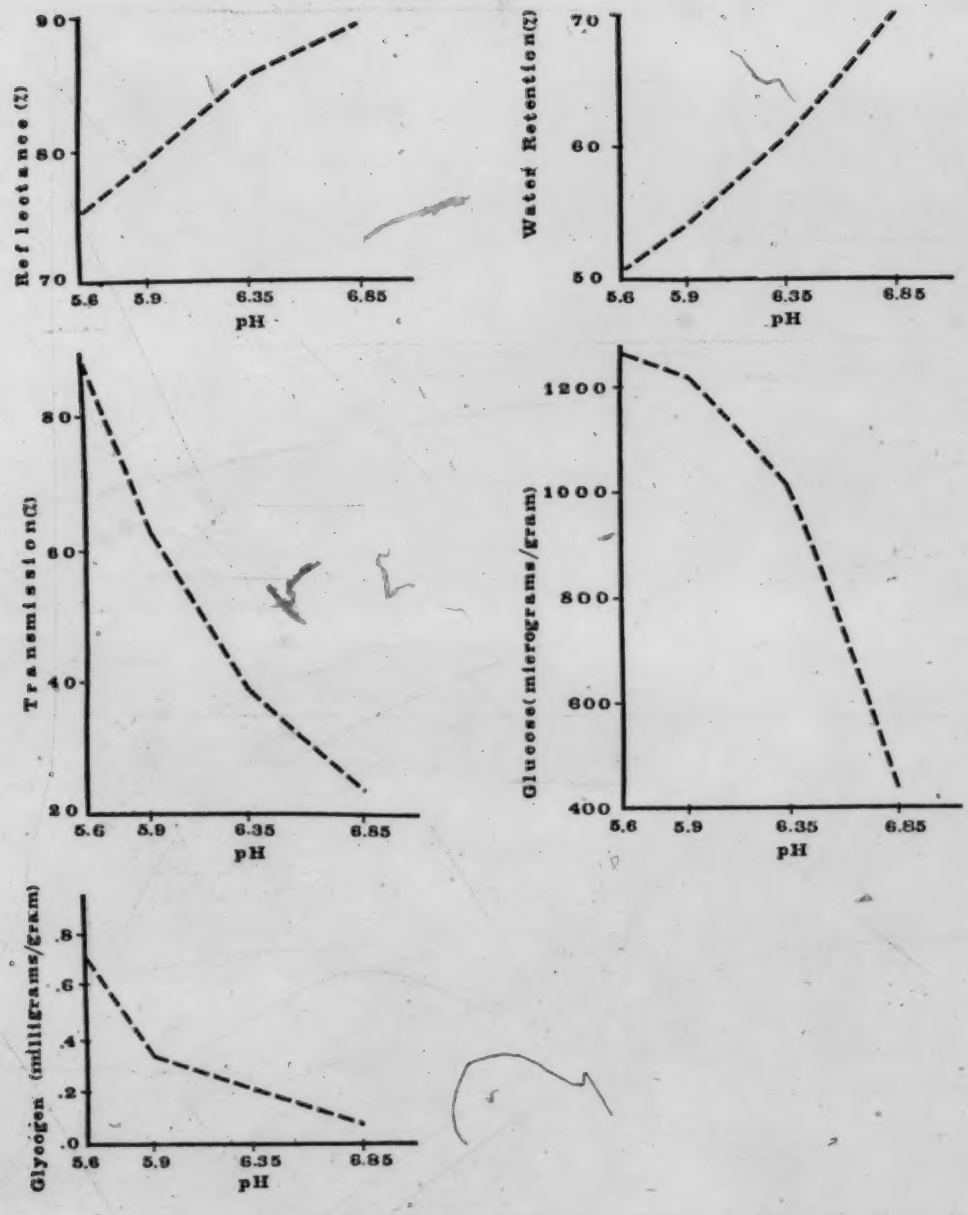

Fig. 1. Relationship of various Longissimus Dorsi muscle properties with 24-hour pH from crossbred bulls.

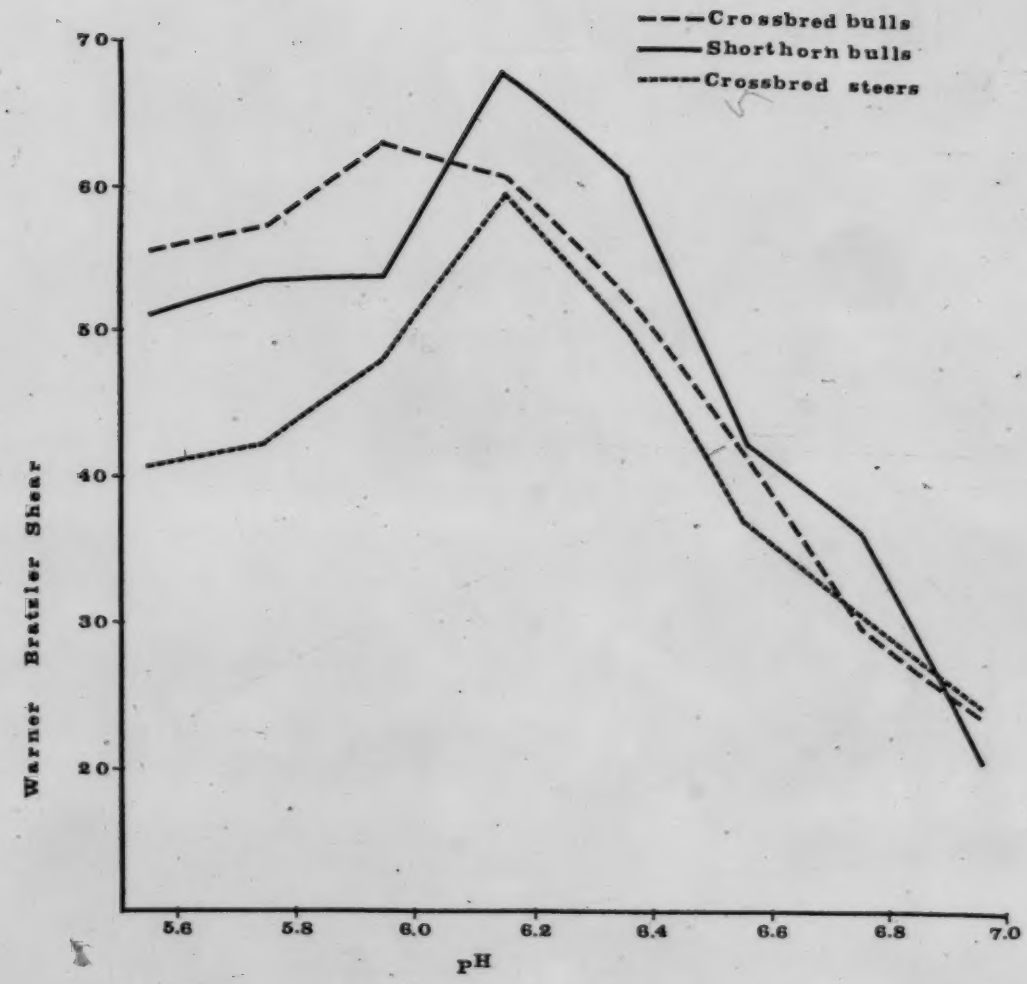

Fig. 2 Relationship of tenderness with 24-hour pH in the Longissimus Dorsi muscle.

markedly increased had analyses been restricted to carcasses with 24-hour pH of 6.2 or greater. Tenderness of LD from steers and Shorthorn bulls in relation to 24-hour pH followed essentially the same pattern as the crossbred bulls. In view of these curvilinear relationships, a single correlation is inadequate to describe the pH-tenderness relationships. It should also be noted that only 7 steers had 24-hour pH greater than 6.2 while 13 Shorthorns and 41 crossbred bulls were in this category.

Estimates of glycogen and glucose in the tissue, and all measures of quality, were based on samples taken 6 days post-mortem. The degree to which the chemical constituents may have changed from 24-hour post-mortem (when pH was recorded) or from immediate pre-slaughter levels cannot be documented from this study. However, Lawrie (1966) has reported that glycogen depletion associated with stress occurs pre-slaughter. Thus the muscle tissue of a stressed animal at the time of slaughter may exhibit low glycogen, low glucose and high pH because of decreased lactic acid content. Water retention of such muscle would also be increased since, as reported by Bouton et al. (1957) the iso-electric point of many muscle proteins is pH 5.5 with increased water binding capacity at higher pH levels.

From results obtained in this study it is clear that pre-slaughter stress did cause depletion of the primary

post-mortem energy reserve (glycogen) with an increase in pH and its subsequent effects on water retention, transmission, and other measures of meat quality. However, the data would support the conclusion that quality changes including color and tenderness are unlikely to be of real importance unless pH is 6.2 or greater. This suggests that the arbitrary cut-off of pH 5.7 suggested by Webb et al. (1967) for classifying dark cutters is probably too low. If a cut-off of 6.1 is applied to the present data, 31.2% of the crossbred bulls, 7% of the crossbred steers and 10.3% of the Shorthorn bulls would have been considered high pH or dark cutting.

No significant age effects were found for meat quality traits for crossbred bulls (Table 5). In earlier work, Martin et al. (1971b) observed that pre-slaughter stress had a larger effect on young (13 month) vs older (15 month) crossbred bulls. In their study, however, the transport time was 7 hours compared with 1 hour for crossbred bulls in the present study and the proportion of animals exhibiting stress was much lower. Significant age effects on meat quality were found for the crossbred steers (Table 6) and the Shorthorn bulls (Table 7). However, the quality of the meat would appear to increase with increase in age rather than decrease.

The crossbred bulls were superior in carcass

composition and chemical composition of the longissimus dorsi muscle to the crossbred steers which were superior to the Shorthorn bulls (Table 1 and 2). Muscle of the primal cuts as a percentage of carcass weight averaged 58.8, 54.4 and 51.9% and total rib-fat depth averaged 2.79, 4.04 and 4.67 centimeters for the crossbred bulls, crossbred steers and Shorthorn bulls respectively. Correlations between muscle of the primal cuts and 24-hour pH and color score were low for all sex-breed groups (Table 3). Correlations between total rib-fat and 24-hour pH and color were low for all sex-breed groups. In view of these low relationships it may be concluded that carcass composition has little relationship to stress-susceptibility and the production of dark beef within this group of animals. Thus selection for increased carcass lean and decreased total rib-fat would probably not lead to a higher incidence of dark cutting beef.

The study of stress as it affects meat quality is important in view of the results of this study since the trend has been toward increased production of entire males for slaughter. To prevent undesirable post-mortem developments in muscle and consequent lowered grades due to dark color, bulls must be shipped to the abattoir without delay or excitement. Whether or not there are breed or breed cross differences in stress susceptibility remains an

open question but there is no doubt that bulls are much more susceptible than steers. Why individual animals, sexes or breeds are more susceptible to ante-morten stress and produce high pH beef post-mortem may lie in the enzymes or substrates of the glycolytic cycle or in the hormones of the endocrine system. Many questions concerning high pH beef remain unanswered and require further research. Why is dark beef extremely tender? What effect does rigor-mortis, cold shortening and aging have on dark beef tenderness? Does Z-line degradation occur with aging of dark beef? Once these questions are answered perhaps a greater degree of control of tenderness and quality in beef could be attained resulting in a more uniform product for the consumer.

6. CONCLUSION

The primary conclusions drawn from this study were:

1. Bulls were found to be more stress-susceptible than steers of the same genetic background with the consequent production of high pH beef.
2. Age effects (i.e. 12 vs 15 months) on meat quality were unimportant.
3. Residual glucose and glycogen in the longissimus dorsi muscle were lower in stress susceptible animals.
4. Carcass composition was not shown to influence the incidence of high pH beef within sex-breed groups.
5. As pH increased meat color darkened, water retention increased, and transmission decreased. Tenderness was found to increase rapidly at pH values above 6.1.
6. Results of this study indicate a pH of greater than 6.1 could be used as an arbitrary cut-off for classifying dark beef from young bulls.

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